

## **METHOD AND AN APPARATUS FOR A WAVEFORM QUALITY MEASUREMENT**

### **Claim of Priority under 35 U.S.C. §120**

[0001] The present Application for Patent is a Continuation and claims priority to Patent Application No. 09/738,586, entitled "METHOD AND AN APPARATUS FOR A WAVEFORM QUALITY MEASUREMENT" filed December 14, 2000, now allowed, and assigned to the assignee hereof and hereby expressly incorporated by reference herein.

### **BACKGROUND**

#### **Field**

[0002] The current invention relates to quality assurance. More particularly, the present invention relates to a method and apparatus for waveform quality measurement.

#### **Background**

[0003] Recently, communication systems have been developed to allow transmission of signals from an origination station to a physically distinct destination station. In transmitting signals from the origination station over a communication link, the signal is first converted into a form suitable for efficient transmission over the communication link. As used herein, the communication link comprises a medium over which a signal is transmitted. Conversion, or modulation, of the signal involves varying a parameter of a carrier wave in accordance with the signal in such a way that the spectrum of the resulting modulated carrier is confined within the communication link bandwidth. At the destination station the original signal is replicated from a version of the modulated carrier received over the communication link. Such a replication is generally achieved by using an inverse of the modulation process employed by the origination station.

[0004] Modulation also facilitates multiple-access, i.e., simultaneous transmission and/or reception, of several signals over a common communication link. Multiple-access communication systems often include a plurality of remote subscriber units requiring intermittent service of relatively short duration rather than continuous access to the common communication link. Several multiple-access techniques are known in

the art, such as time division multiple-access (TDMA), frequency division multiple-access (FDMA), and amplitude modulation (AM). Another type of a multiple-access technique is a code division multiple-access (CDMA) spread spectrum system that conforms to the "TIA/EIA/IS-95 Mobile Station-Base Station Compatibility Standard for Dual-Mode Wide-Band Spread Spectrum Cellular System," hereinafter referred to as the IS-95 standard. The use of CDMA techniques in a multiple-access communication system is disclosed in U.S. Patent No. 4,901,307, entitled "SPREAD SPECTRUM MULTIPLE-ACCESS COMMUNICATION SYSTEM USING SATELLITE OR TERRESTRIAL REPEATERS," and U.S. Patent No. 5,103,459, entitled "SYSTEM AND METHOD FOR GENERATING SIGNAL WAVEFORMS IN A CDMA CELLULAR TELEPHONE SYSTEM," both assigned to the assignee of the present invention and incorporated herein by reference.

[0005] FIG. 1 illustrates an ideal waveform 100 of an embodiment of a code division communication system in accordance with the IS-95 standard. For the purposes of this document, a waveform is a manifestation, representation or visualization of a wave, pulse or transition. The idealized waveform 100 comprises parallel channels 102 distinguished from one another by a cover code. The cover code in a communication system according to the IS-95 standard comprises Walsh codes. The ideal waveform 100 is then quadrature spreaded, baseband filtered and upconverted on a carrier frequency. The resulting modulated waveform 100, is expressed as:

$$s(t) = \sum_i R_i(t) e^{-j\omega_c t} \quad (1)$$

where:

$\omega_c$  is the nominal carrier frequency of the waveform;

$i$  is the index of the code channels summation; and

$R_i(t)$  is the complex envelope of the ideal  $i$ -th code channel.

Equipment, e.g., a transmitter of the code division communication system, generates actual waveform  $x(t)$  that is different from the ideal waveform. Such an actual waveform  $x(t)$  is expressed as:

$$x(t) = \sum_i b_i [R_i(t + \tau_i) + E_i(t)] \cdot e^{-j[(\omega_c + \Delta\omega)(t + \tau_i) + \theta_i]} \quad (2)$$

where:

$b_i$  is the amplitude of the ideal waveform relative to the ideal waveform for the  $i_{th}$  code channel;

$\tau_i$  is the time offset of the ideal waveform relative to the ideal waveform for the  $i_{th}$  code channel;

$\Delta\omega$  is the radian frequency offset of the signal;

$\theta_i$  is the phase offset of the ideal waveform relative to the ideal waveform for the  $i_{th}$  code channel; and

$E_i(t)$  is the complex envelope of the error (deviation from ideal) of the actual transmit signal for the  $i$ -th code channel.

[0006] The difference between the ideal waveform  $s(t)$  and the actual waveform  $x(t)$  is measured in terms of frequency tolerance, pilot time tolerance, and waveform compatibility. One method to perform such a measurement is to determine modulation accuracy defined as a fraction of power of the actual waveform  $x(t)$  that correlates with the ideal waveform  $s(t)$ , when the transmitter is modulated by the code channels. The modulation accuracy is expressed as:

$$\rho_{\text{overall}} = \frac{\int_{T_1}^{T_2} |s(t) \cdot x(t)^*| \cdot dt}{\left\{ \int_{T_1}^{T_2} |s(t)|^2 \cdot dt \right\} \cdot \left\{ \int_T |x(t)|^2 \cdot dt \right\}} \quad (3)$$

where:

$T_1$  is beginning of the integration period; and

$T_2$  is the end of the integration period.

[0007] For discrete time systems, where  $s(t)$  and  $x(t)$  are sampled at ideal sampling points  $t_k$ , Equation 3 can be written as:

$$\rho_{\text{overall}} = \frac{\sum_{k=1}^N |S_k \cdot X_k^*|^2}{\left\{ \sum_{k=1}^N |S_k|^2 \right\} \cdot \left\{ \sum_{k=1}^N |X_k|^2 \right\}} \quad (4)$$

where:

$X_k = x[k] = x(t_k)$  is  $k_{th}$  sample of the actual waveform; and

$S_k = s[k] = s(t_k)$  is the corresponding  $k_{th}$  sample of the ideal waveform.

[0008] A multiple-access communication system may carry voice and/or data. An example of a communication system carrying both voice and data is a system in accordance with the IS-95 standard, which specifies transmitting voice and data over the communication link. A method for transmitting data in code channel frames of fixed size is described in detail in U.S. Patent No. 5,504,773, entitled "METHOD AND APPARATUS FOR THE FORMATTING OF DATA FOR TRANSMISSION," assigned to the assignee of the present invention and incorporated by reference herein. In accordance with the IS-95 standard, the data or voice is partitioned into code channel frames that are 20 milliseconds wide with data rates as high as 14.4 Kbps. Additional examples of communication systems carrying both voice and data comprise communication systems conforming to the "3rd Generation Partnership Project" (3GPP), embodied in a set of documents including Document Nos. 3G TS 25.211, 3G TS 25.212, 3G TS 25.213, and 3G TS 25.214 (the W-CDMA standard), or "TR-45.5 Physical Layer Standard for cdma2000 Spread Spectrum Systems" (the IS-2000 standard). Such communication systems use a waveform similar to the one discussed above.

[0009] Recently, a data only communication system for a high data rate (HDR) transmission has been developed. Such a communication system has been disclosed in co-pending application serial number 08/963,386, entitled "METHOD and apparatus FOR HIGH RATE PACKET DATA transmission," filed November 3, 1997, now U.S. Patent No. 6,574,211B2, issued on June 3, 2003, assigned to the assignee of the present invention and incorporated by reference herein. The HDR communication system defines a set of data rates, ranging from 38.4 kbps to 2.4 Mbps, at which an origination terminal (access point, AP) may send data packets to a receiving terminal (access terminal, AT). The HDR system utilizes a waveform with channels distinguished both in time domain and code domain.

[0010] FIG. 2 illustrates such a waveform 200, modeled after a forward link waveform of the above-mentioned HDR system. The waveform 200 is defined in terms of frames 202. (Only frames 202a, 202b, and 202c are shown in FIG. 2.) In an exemplary embodiment, a frame comprises 16 time slots 204, each time slot 204 being 2048 chips

long, corresponding to a 1.67 millisecond slot duration, and, consequently, a 26.67 ms frame duration. Each slot 204 is divided into two half-slots 204a and 204b, with pilot bursts 206a and 206b transmitted within each half-slot 204a and 204b. In an exemplary embodiment, each pilot burst 206a and 206b is 96 chips long, and is centered at the midpoint of its associated half-slot 204a and 204b. The pilot bursts 206a and 206b comprise a pilot channel signal covered by a Walsh cover with index 0. The pilot channel is used for synchronization purposes. A forward medium access control channel (MAC) 208 forms two bursts 208a and two bursts 208b of a length of 64 chips each. The MAC bursts 208a and 208b are transmitted immediately before and immediately after the pilot bursts 206a and 206b of each slot 204. In an exemplary embodiment, the MAC is composed of up to 63 code channels, which are orthogonally covered by 64-ary Walsh codes. Each code channel is identified by a MAC index, which has a value between 0 and 63 and identifies the unique 64-ary Walsh cover. The MAC indexes 0 and 1 are reserved. A reverse power control channel (RPC) is used to regulate the power of the reverse link signals for each subscriber station. The RPC is assigned to one of the available MACs with MAC index 5-63. The MAC with MAC index 4 is used for a reverse activity channel (RA), which performs flow control on a reverse traffic channel. The forward link traffic channel and control channel payload is sent in the remaining portions 210a of the first half-slot 204a and the remaining portions 210b of the second half-slot 204b. The forward traffic channel and control channel data are encoded, scrambled, and interleaved. The interleaved data are modulated, repeated, and punctured, as necessary. Then, the resulting sequences of modulation symbols are demultiplexed to form 16 pairs (in-phase and quadrature) of parallel streams. Each of the parallel streams is covered with a distinct 16-ary Walsh cover, yielding a code-distinguished channel 212.

[0011] The ideal waveform 200 is then quadrature spreaded, baseband-filtered and upconverted on a carrier frequency. The resulting modulated waveform 200, is expressed as:

$$s(t) = \sum_{i(t)} R_i(t) e^{-j\omega_c t} \quad (5)$$

where:

$\omega_c$  is the nominal carrier frequency of the waveform;

$i(t)$  is the index of the code channels. The index is time dependent as the number of code channels varies with time; and

$R_i(t)$  is the complex envelope of the ideal  $i$ -th code channel, given as:

$$R_i(t) = a_i \left[ \sum_k g(t - kT_c) \cos(\phi_{i,k}) + j \sum_k g(t - kT_c) \sin(\phi_{i,k}) \right] \quad (6)$$

where:

$a_i$  is the amplitude of the  $i$ th code channel;

$g(t)$  is the unit impulse response of the baseband transmit filter;

$\phi_{i,k}$  is the phase of the  $k$ th chip for the  $i$ th code channel, occurring at discrete time  $t_k = kT_c$ .

$T_c$  is a chip duration.

The transmitter of the HDR communication system generates an actual waveform  $x(t)$ , given as:

$$x(t) = \sum_{i(t)} b_i [R_i(t + \tau_i) + E_i(t)] \cdot e^{-j[(\omega_c + \Delta\omega)(t + \tau_i) + \theta_i]} \quad (7)$$

where

$b_i$  is the amplitude of the ideal waveform relative to the ideal waveform for the  $i$ th code channel;

$\tau_i$  is the time offset of the ideal waveform relative to the ideal waveform for the  $i$ th code channel;

$\Delta\omega$  is the radian frequency offset of the signal;

$\theta_i$  is the phase offset of the ideal waveform relative to the ideal waveform for the  $i$ th code channel; and

$E_i(t)$  is the complex envelope of the error (deviation from ideal) of the actual transmit signal for the  $i$ -th code channel.

**[0012]** Based on the complex time domain and code domain channelization of the waveform 200, the waveform quality measurement methods based on code domain channelization are inapplicable. Consequently, there is a need in the art for a method

and an apparatus for a waveform quality measurement for waveforms channelized both in time domain and code domain.

### SUMMARY

[0013] The present invention is directed to a novel method and apparatus for waveform quality measurement. According to the method, an actual signal, representing a waveform divided into channels both in time domain and in code domain is generated. Such an actual waveform can be generated, for example, by a communication system. Test equipment generates an ideal waveform corresponding to the actual waveform. The test equipment then generates an estimate of offsets between parameters of the actual waveform and the ideal waveform, and uses the offsets to compensate the actual waveform. In one embodiment, overall modulation accuracy is evaluated in accordance with the compensated ideal waveform and the ideal waveform.

[0014] In another embodiment, modulation accuracy for a particular time division channel of the waveform is evaluated. The compensated actual waveform is processed to provide the particular time division channel. In one implementation, the processing comprises assigning the compensated actual signal a value that is non-zero in intervals where the particular time division channel is defined and non-zero elsewhere. In another implementation, the processing comprises a multiplication of the compensated actual waveform by a function with a value that is non-zero in intervals where the particular time division channel is defined and zero elsewhere. In one implementation, the ideal waveform is processed in the same manner. In another implementation, the ideal waveform containing the particular time division channel is generated directly. The modulation accuracy for the particular time division channel is evaluated in accordance with the processed compensated actual waveform and the processed ideal waveform.

[0015] In yet another embodiment, code domain power coefficients for a particular code channel are evaluated. The particular time division channel, which contains the particular code channel of the compensated actual waveform, is obtained according to the above-described methods. In one implementation, the ideal waveform is processed in the same manner. In another implementation, the ideal waveform containing the particular code channel of the particular time division channel is generated directly. The modulation accuracy for the particular time division channel is evaluated in

accordance with the processed compensated actual waveform and the processed ideal waveform.

### **BRIEF DESCRIPTION OF THE DRAWINGS**

[0016] The features, objects, and advantages of the present invention will become more apparent from the detailed description set forth below when taken in conjunction with the drawings in which like reference characters identify correspondingly throughout and wherein:

**FIG. 1** illustrates an idealized waveform of a code division communication system;

**FIG. 2** illustrates an idealized waveform of an HDR communication system; and

**FIG. 3** illustrates a concept of an apparatus capable of implementing waveform quality measurement in accordance with the principles of this invention.

### **DETAILED DESCRIPTION**

[0017] **FIG. 3** illustrates a concept of an apparatus capable of implementing waveform quality measurement for waveforms channelized both in time domain and in code domain, such as the exemplary waveform 200 from **FIG. 2**.

[0018] In one embodiment, actual signal  $x(t)$  (representing waveform 200 from **FIG. 2**) enters compensation block 302. The compensation block 302 is also provided with estimates of offsets of the actual waveform  $x(t)$  with respect to an ideal waveform  $s(t)$  from an optimization block 304. The compensation block 302 uses the offset estimates to provide a compensated waveform  $y(t)$ . The compensated waveform  $y(t)$  is provided to a downconversion block 306. The downconverted signal is then provided to an optional sampling block 308. The sampled waveform  $z_s[k]$  is provided to an optional baseband transformation block 310. The output waveform  $z[k]$  from the optional baseband transformation block 310 is provided to a processing block 312.

[0019] In one embodiment, the ideal waveform  $s(t)$  is generated by a signal generator 314. The ideal waveform  $s(t)$  is provided to an optional sampling block 316. The sampled waveform  $ss[k]$  is provided to an optional baseband transformation block 318. The output waveform  $r[k]$  from the optional baseband transformation block 318 is provided to a processing block 312. In another embodiment, the signal generator 314



generates the digital waveform  $r[k]$  directly. Therefore, in such an embodiment, the sampling block 316 and the optional baseband transformation block 318 are not needed.

[0020] The processing block 312 uses signals  $z[k]$  and  $r[k]$  to calculate waveform characteristics.

[0021] As discussed, the actual waveform  $x(t)$  will be offset from the ideal waveform  $s(t)$  in frequency, time and phase. The waveform quality measurement is determined for the best alignment between the actual waveform  $x(t)$  will be offset from the ideal waveform  $s(t)$ . Consequently, the waveform quality measurement is evaluated for a plurality of combinations of frequency, time, and phase offsets, and the maximum of such evaluations is taken as a figure of merit. The function of optimization block 304 is to generate the plurality of combinations of frequency, time, and phase offsets.

[0022] The function of the compensation block 302 is to operate on the waveform  $x(t)$  to provide compensated waveform  $y(t)$ , given by Equation 7:

$$y(t) = x(t - \hat{\tau}_0) e^{j[\Delta\hat{\omega}t + \hat{\theta}_0]} \quad (8)$$

where:

$\Delta\hat{\omega}$  - an estimate of radian frequency offset of the signal  $x(t)$  with respect to signal  $s(t)$ ;

$\hat{\tau}_0$  - an estimate of time offset of the signal  $x(t)$  with respect to signal  $s(t)$ ;

$\hat{\theta}_0$  - an estimate of phase offset of the signal  $x(t)$  with respect to signal  $s(t)$ .

The  $\Delta\hat{\omega}$ ,  $\hat{\tau}_0$ ,  $\hat{\theta}_0$  are provided to the compensation block 302 by the optimization block 304.

[0023] As discussed, the waveform  $x(t)$  was upconverted on a carrier frequency, the purpose of the downconversion block 306 is to downconvert the compensated waveform  $y(t)$  to a baseband waveform  $z(t)$ .

[0024] In one embodiment, the optional sampling block 308 creates discrete version  $z[k]$  of the waveform  $z(t)$  by sampling the waveform  $z(t)$  at the ideal sampling points  $t_k$ :

$$z[k] = z(t_k); \forall k \quad (9)$$

In another embodiment, the optional sampling block 308 is omitted and the sampling is performed by the processing block 312 after baseband transformation.

[0025] As discussed, the waveform 200 is baseband filtered before transmission. Consequently, the optional baseband transformation block 310 is utilized to remove inter-symbol interference (ISI) introduced by the transmitter filter. To accomplish this, the transfer function of the baseband transformation block 310 is an inverse complex conjugate of the transfer function of the ideal transmitter filter.

[0026] The processing block 312 operates on the signals  $z[k]$  and  $r[k]$  to provide the required waveform quality measurement as described in detail below. In one embodiment, when the optional sampling block 308 has been omitted, the processing block 312 creates a discrete  $z[k]$  version of the signal  $z(t)$  by sampling the signal  $z(t)$  at the ideal sampling points  $t_k$  in accordance with Equation 9.

[0027] Considering the above-described apparatus, one of ordinary skills in the art will be able to modify the block schematics to different representation of the waveforms  $x(t)$  and  $s(t)$ . For example, if the waveform  $x(t)$  is represented as a baseband signal in a digital domain, a downconversion block 306 and an optional sampling block 308 need not be present. Furthermore, if the waveform  $x(t)$  has not been filtered, an optional baseband transformation block 310 need not be present. Furthermore, one of ordinary skills in the art will be able to modify the block schematics according to a type of measurement to be performed. For example, if an effect of a baseband filter is to be ascertained, the baseband transformation blocks 310 and 318 would be omitted; thus, the processing block 312 would be provided with the ideal waveform and the ideal waveform from sampling blocks 308 and 316.

### **Modulation Accuracy Measurement**

[0028] Modulation accuracy is defined as a fraction of power in the actual waveform  $z[k]$  that correlates with the ideal waveform  $r[k]$ , when the transmitter is modulated by at least one channel in the waveform.

[0029] An overall modulation accuracy is defined as a fraction of power in the actual waveform  $z[k]$  that correlates with the ideal waveform  $r[k]$  when the transmitter is modulated by all the channels in the waveform. In the exemplary embodiment of the HDR communication system, these channels comprise the Pilot Channel, the MAC

Channel and the Forward Traffic or Control Channel. The first overall modulation accuracy is defined as follows:

$$\rho_{\text{overall-1}} = \frac{N \cdot \sum_{j=1}^N \left| \sum_{k=1}^M Z_{j,k} R_{j,k}^* \right|^2}{\left\{ \sum_{j=1}^N \sum_{k=1}^M |R_{j,k}|^2 \right\} \cdot \left\{ \sum_{j=1}^N \sum_{k=1}^M |Z_{j,k}|^2 \right\}} \quad (10)$$

where:

$\rho_{\text{overall-1}}$  is the first overall modulation accuracy;

$j$  is an index designating an elementary unit of a waveform;

$N$  is a summation limit designating number of elementary units;

$k$  is an index designating a sample in the elementary unit;

$M$  is a summation limit designating number of samples in the elementary unit;

$Z_{j,k} = z[M(j-1)+k]$  is a  $k$ th sample in the  $j$ th elementary unit of the actual waveform; and

$R_{j,k} = r[M(j-1)+k]$  is a  $k$ th sample in the  $j$ th elementary unit of the ideal waveform.

[0030] An elementary unit is defined as a minimum waveform span defining a complete channel structure. The value of the summation limit  $N$  is chosen so that a noise variance of the measurement is below a required value.

[0031] Applying Equation 10 to the waveform 200 of a forward link of the HDR system, the elementary unit is a half-slot; consequently, the summation limit  $M = 1024$ . The first sample,  $z(t1)$ , occurs at the first chip of a half slot and the final sample,  $z(t1024N)$ , occurs at the last chip of a half slot. The value of the summation limit  $N$  has been determined to be at least 2.

[0032] The first overall modulation accuracy fails to account for possible discontinuities of parameters of the waveform on the borders of the elementary units. Consequently, a second overall modulation accuracy is defined as follows:

$$\rho_{\text{overall-2}} = \frac{N \cdot \sum_{j=1}^N \left| \sum_{k=\frac{M}{2}+1}^{M+\frac{M}{2}+1} Z_{j,k} R_{j,k}^* \right|^2}{\left\{ \sum_{j=1}^N \sum_{k=\frac{M}{2}+1}^{M+\frac{M}{2}+1} |R_{j,k}|^2 \right\} \cdot \left\{ \sum_{j=1}^N \sum_{k=\frac{M}{2}+1}^{M+\frac{M}{2}+1} |Z_{j,k}|^2 \right\}} \quad (11)$$

where:

$\rho_{\text{overall-2}}$  is the second overall modulation accuracy;

$j$  is an index designating an elementary unit of a waveform;

$N$  is a summation limit designating number of elementary units;

$k$  is an index designating a sample in the elementary unit;

$M$  is a summation limit designating number of samples in the elementary unit;

$Z_{j,k} = z[(M + \frac{M}{2} + 1) \cdot (j - 1) + k]$  is a  $k_{\text{th}}$  sample in the  $j_{\text{th}}$  elementary unit of the

actual waveform; and

$R_{j,k} = r[(M + \frac{M}{2} + 1) \cdot (j - 1) + k]$  is a  $k_{\text{th}}$  sample in the  $j_{\text{th}}$  elementary unit of the

ideal waveform.

[0033] Applying Equation 11 to the waveform 200 of a forward link of the HDR system, the elementary unit is a half-slot; consequently, the summation limit  $M = 1024$ . The first sample,  $z(t531)$ , occurs at the 513th chip of a half slot and the final sample,  $z(t1536N)$ , occurs at the 513th chip of the last half slot. The value of the summation limit  $N$  has been determined to be at least 2.

[0034] A time division channel (TD\_channel) modulation accuracy is defined as a fraction of power in the actual waveform  $z[k]$  that correlates with the ideal waveform  $r[k]$  when the transmitter is modulated by the particular TD\_channel in the waveform. In the exemplary embodiment of the HDR communication system, the channels comprise the Pilot Channel, the MAC Channel and the Forward Traffic or Control Channel. The TD\_channel modulation accuracy is defined as follows:

$$\rho_{\text{TD\_channel}} = \frac{N \cdot \sum_{j=1}^N \left| \sum_{k=1}^M Z_{j,k} R_{j,k}^* \right|^2}{\left\{ \sum_{j=1}^N \sum_{k=1}^M |R_{j,k}|^2 \right\} \cdot \left\{ \sum_{j=1}^N \sum_{k=1}^M |Z_{j,k}|^2 \right\}} \quad (12)$$

where:

$\rho_{TD\_channel}$  is the modulation accuracy for the time division channel identified by an index  $TD\_channel$ ;

$j$  is an index designating an elementary unit of a waveform;

$N$  is a summation limit designating number of elementary units;

$k$  is an index designating a sample in the elementary unit;

$M$  is a summation limit designating number of samples in the elementary unit;

$Z_{j,k} = z[M(j-1)+k]$  is a  $k_{th}$  sample in the  $j_{th}$  elementary unit of the actual  $TD\_channel$ ; and

$R_{j,k} = r[M(j-1)+k]$  is a  $k_{th}$  sample in the  $j_{th}$  elementary unit of the ideal  $TD\_channel$ .

[0035] The concept of processing the actual waveform  $z[k]$  and the ideal waveform  $r[k]$  to obtain a particular  $TD\_channel$  is described next. A function  $g_{TD\_channel}$  is defined:

$$g_{TD\_channel}[k] = \begin{cases} 1 & \text{if } \begin{cases} m_1 \leq (k \bmod L) \leq m_2 \\ m_3 \leq (k \bmod L) \leq m_4 \\ \vdots \\ m_{n-1} \leq (k \bmod L) \leq m_n \end{cases} \\ 0 & \text{elsewhere} \end{cases} \quad (13)$$

where:

$m_p \leq (k \bmod L \leq m_{p+1})$  for  $p = 1, 2, \dots, n$ , defines intervals where the waveform is nonzero for the particular  $TD\_channel$ ; and

$L$  interval of an elementary unit of the signal  $z[k]$ .

Then, the actual waveform  $z[k]$  and the ideal waveform  $r[k]$  are multiplied by the function  $g_{TD\_channel}[k]$ , to yield the particular  $TD\_channels$ :

$$\begin{aligned} z'[k] &= z[k] \cdot g_{TD\_channel}[k] \\ r'[k] &= r[k] \cdot g_{TD\_channel}[k] \end{aligned} \quad (14)$$

[0036] One of ordinary skills in the art will understand that the implementation of the concept can vary. In one embodiment, the processing is implemented as a multiplication of the waveform by a function with a value that is non-zero in intervals

where the particular time division channel is defined and zero elsewhere. In another embodiment, the processing comprises assigning the waveform a value that is non-zero in intervals to where the particular time division channel and zero elsewhere. In yet another embodiment, the processing unit, implementing Equation (12) is configured to carry the internal summations as follows:

$$\sum_{k=1}^M = \sum_{m_1}^{m_2} + \sum_{m_3}^{m_4} + \dots + \sum_{m_{n-1}}^{m_n} \quad (15)$$

where:

$m_p \leq (k \bmod L \leq m_{p+1})$  for  $p = 1, 2, \dots, n$ , defines interval where the waveform is nonzero for the particular TD\_channel; and

L interval of an elementary unit of the signals  $z[k]$  and  $r[k]$ .

### Code Domain Measurement

[0037] Code domain power is defined as a fraction of power of the signal  $z(t_k)$  that correlates with each code channel  $R_i(t_k)$  when the transmitter is modulated according to a known code symbol sequence. The concept of processing the waveform to obtain each code channel  $R_i(t_k)$  is described next. First, a particular TD\_channel containing each code channel  $R_i(t_k)$  is obtained, utilizing any of the above-outlined methods. For example, Equation 13 is used to obtain function  $g_{TD\_channel}[k]$  for the particular TD\_channel. The function  $g_{TD\_channel}[k]$  is then used to operate on the actual waveform  $z[k]$  and the i-th code channel  $R_i[k]$  of the ideal signal  $r[k]$  to obtain waveforms:

$$\begin{aligned} z'[k] &= z[k] \cdot g_{TD\_channel}[k] \\ R'_i[k] &= R_i[k] \cdot g_{TD\_channel}[k] \end{aligned} \quad (16)$$

The waveform quality code domain power coefficients  $\rho_{TD\_channel,i}$  for the particular TD\_channel are then defined for each code channel  $R_i(t_k)$  as follows:

$$\rho_{TDM\_channel,i} = \frac{N \cdot \sum_{j=1}^N \left| \sum_{k=1}^M Z_{j,k} R'_{i,j,k} \right|^2}{\left\{ \sum_{j=1}^N \sum_{k=1}^M |R'_{i,j,k}|^2 \right\} \cdot \left\{ \sum_{j=1}^N \sum_{k=1}^M |Z_{j,k}|^2 \right\}}, \quad i = w_1, \dots, w_v \quad (17)$$

where:

$\rho_{TDM\_channel,i}$  is the code domain coefficient for a time division channel identified by an index  $TD\_channel$  and a code channel  $R_i[k]$  identified by index  $i$ ;

$w_1$  is a first code channel for the time division channel  $TDM\_channel$ ;

$w_v$  is a last code channel for time division channel  $TDM\_channel$ ;

$j$  is an index designating an elementary unit of waveforms;

$N$  is a summation limit designating a number of elementary units;

$k$  is an index designating a sample in the elementary unit;

$M$  is a summation limit designating number of samples in the elementary units;

$Z_{j,k} = z[M(j-1) + k]$  is a  $k$ th sample in the  $j$ th elementary unit of the filtered signal; and

$R'_{i,j,k} = R'_i[M(j-1) + k]$  is a  $k$ th sample in the  $j$ th elementary unit of the  $i$ -th code channel of the ideal signal.

[0038] For example, applying the above-described method to evaluate  $\rho_{MAC,i}$ , of the waveform **200** of a forward link of the HDR system, the elementary unit is a half-slot; consequently, the summation limit  $M = 1024$ . From Equation (13) and **FIG. 2**:

$$g_{MAC}[k] = \begin{cases} 1 & \text{if } \begin{cases} 401 \leq (k \bmod 1024) \leq 464 \\ 561 \leq (k \bmod 1024) \leq 624 \end{cases} \\ 0 & \text{elsewhere} \end{cases} \quad (18)$$

where  $(k \bmod 1024) = 1$  occurs at the first chip of every half slot. Then, Equation (16) yields:

$$\begin{aligned} z[k] &= z[k] \cdot g_{MAC}[k] \\ R'_i[k] &= R'_i[k] \cdot g_{MAC}[k] \end{aligned} \quad (19)$$

The following code domain power coefficients  $\rho_{MAC,i}$  are defined for the MAC Channel by Equation (17):

$$\rho_{MAC,i} = \frac{N \cdot \sum_{j=1}^N \left| \sum_{k=1}^{1024} Z_{j,k}'' R_{i,j,k}''^* \right|^2}{\left\{ \sum_{j=1}^N \sum_{k=1}^{1024} |R_{i,j,k}''|^2 \right\} \cdot \left\{ \sum_{j=1}^N \sum_{k=1}^{1024} |Z_{j,k}''|^2 \right\}}, \quad i = 2, \dots, 63 \quad (20)$$

[0039] The value of N for the measurement of  $\rho_{MAC,i}$  for  $i \neq 4$  has been determined to be at least 16. The first sample,  $z(t_1)$ , occurs at the first chip of a half slot and the final sample,  $z(t_{1024N})$ , occurs at the last chip of a half slot.

[0040] Those of skill in the art would understand that the various illustrative logical blocks, modules, circuits, and algorithm steps described in connection with the embodiments disclosed herein may be implemented as electronic hardware, computer software, or combinations of both. The various illustrative components, blocks, modules, circuits, and steps have been described generally in terms of their functionality. Whether the functionality is implemented as hardware or software depends upon the particular application and design constraints imposed on the overall system. Skilled artisans recognize the interchangeability of hardware and software under these circumstances, and how best to implement the described functionality for each particular application.

[0041] As examples, the various illustrative logical blocks, modules, circuits, and algorithm steps described in connection with the embodiments disclosed herein may be implemented or performed with a digital signal processor (DSP), an application specific integrated circuit (ASIC), a field programmable gate array (FPGA) or other programmable logic device, discrete gate or transistor logic, discrete hardware components, such as, e.g., registers and FIFO, a processor executing a set of firmware instructions, any conventional programmable software module and a processor, or any combination thereof. The processor may advantageously be a microprocessor, but in the alternative, the processor may be any conventional processor, controller, microcontroller, or state machine. The software module could reside in RAM memory, flash memory, ROM memory, registers, hard disk, a removable disk, a CD-ROM, or



any other form of storage medium known in the art. Those of skill would further appreciate that the data, instructions, commands, signals, bits, symbols, and chips that may be referenced throughout the above description are advantageously represented by voltages, currents, electromagnetic waves, magnetic fields or particles, optical fields or particles, or any combination thereof.

[0042] The previous description of the preferred embodiments, using communication systems to exemplify measurement of waveform quality, is provided to enable any person skilled in the art to make or use the present invention. The various modifications to these embodiments will be readily apparent to those skilled in the art, and the generic principles defined herein may be applied to other embodiments without the use of the inventive faculty. Specifically, one of ordinary skills in the art will understand that the generic principles disclosed apply equally to any like waveform regardless of the equipment that generated the waveform. Thus, the present invention is not intended to be limited to the embodiments shown herein but is to be accorded the widest scope consistent with the principles and novel features disclosed herein.

[0043] **WHAT IS CLAIMED IS:**